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Characterization of regenerative agricultural practices and drivers of their adoption in mixed farming systems

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ABSTRACT

Despite regional efforts to promote regenerative agriculture (RA), its contribution to the global food market has remained insignificant. This low market contribution has been attributed to the low adoption of regenerative agricultural practices (RAPs). Increasing the adoption of RAPs is crucial for sustainable agricultural production, maintaining production resources, and reducing production costs, ultimately increasing market share. Therefore, this study aimed to characterize RAPs in mixed farms and examine the factors driving their adoption. The study was conducted in Trans-Nzoia and Uasin Gishu counties, Kenya. A cross-sectional questionnaire survey was conducted to collect primary data from 397 farms using a multi-stage sampling approach. Data on RAPs, their distribution, challenges, and drivers of adoption were collected. The findings revealed that fodder production, managed grazing, the use of crop residue as feed, diversification of animal and plant species, and legume production had high adoption rates. Intercropping, retaining crop residue, crop rotation, and agroforestry practices had moderate adoption rates. Composting, mulching, zero-tillage, organic farming, water harvesting, irrigation, terracing, ridge construction, and integrated pest management had low adoption. Additionally, 39.55%, 59.95%, and 0.50% of the farms had low, moderate, and high adoption of RAPs, respectively. The binary logistic regression model showed that adoption was positively influenced by farmer training, farmers' attitudes, benefit level, land ownership status, crop type, and subsidy programs. The study established that adoption of RAPs was low. Therefore, improved farmer training, targeted subsidy programs, and streamlined processing of land title deeds are recommended to accelerate adoption.

Contribution/Originality: This study is among the few that have investigated and enhanced the understanding of regenerative agricultural practices, their drivers, and adoption levels in mixed farming systems in Sub-Saharan Africa. The study has the potential to stimulate the adoption of regenerative agriculture in the region, thereby improving food production and sustainability.

1. INTRODUCTION

Agriculture remains the main economic sector in Kenya, accounting for 75% of the national exports and 60% of total employment, respectively, and 26% and 27% of the Gross Domestic Product (GDP) directly and indirectly, respectively (Central Bank of Kenya, 2023; MoALF, 2017, 2023). The sector largely consists of smallholder farmers who cultivate about 90% of the arable land in the country. These farmers contribute nearly 75% of the overall production, accounting for 80% of the agricultural GDP (Birch, 2018; MoALF, 2019). They engage in mixed production systems, integrating livestock and crop production, which enhances land productivity, nutrient cycling, increases output, and minimizes reliance on synthetic inputs (MoALF&C, 2020; Rudel et al., 2016). However, this sector faces numerous challenges, primarily land degradation that affects 37% of Kenya's farmland. Coupled with the pressures of a growing population and climate extremes, it has led to soil erosion, biodiversity loss, a decline in soil fertility, and pollution of water sources (Çakmakçı, Salık, & Çakmakçı, 2023; Kogo, Kumar, & Koech, 2021).

Owing to the aforementioned challenges, agricultural performance has stagnated, with growth rates declining from 4.7% in the first decade post-independence to about 2% in the 1990s and -2.4% in the 2000s (Alila & Rosemary, 2019). The Economic Survey reported a growth rate of -0.4% in 2021 and a further contraction of 1.6% in 2022 (Central Bank of Kenya, 2023). The main crops, such as maize, declined in production from 44.6 million bags in 2018 to 34.3 million bags in 2022, with average productivity remaining below 20 bags per hectare since 2010, contrary to the expectation of at least 25 bags per hectare (Alila & Rosemary, 2019; Birch, 2018; CCAFS, 2020; Faostat, 2021). The dairy sector also faces productivity challenges that result in a supply shortage (U.S. Department of Agriculture (USDA), 2024). Despite an increase in milk production in 2020, a decline was experienced from 2021 to 2023, with the quantities dropping from 4.63 billion kg to 4.57 billion kg in 2023. This was contrary to the steadily rising number of dairy farmers registered in societies from 2020 to 2023 (Maritime, 2024).

Farmers have intensified production as one of the alternatives for achieving increased farm productivity, owing to limited and finite arable land that is continuously dwindling (Pretty, Toulmin, & Williams, 2011; Schut, van Paassen, Leeuwis, & Klerkx, 2021). Intensification has been accompanied by increased use of external farm inputs such as agrochemicals, inorganic fertilizers, irrigation systems, improved varieties, and genetic modification of species (FAO, 2018). Though some of the strategies have resulted in increased production, they are costly, have instigated a reduction in soil fertility, loss of biodiversity, and further increased emissions of GHGs that contribute to climate change and adversely affect the environment, consequently leading to unsustainable farming systems (Giller, Hijbeek, Andersson, & Sumberg, 2021; Schipanski et al., 2016). As a result, smallholder farmers are left vulnerable to low productivity, loss of natural resources, and food insecurity (Gitz, Meybeck, Lipper, Young, & Braatz, 2016).

Regenerative Agriculture (RA) has been proposed as a sustainable solution to increase productivity through agricultural practices that promote ecological sustainability (Giller et al., 2021; Jayasinghe, Thomas, Anderson, Chen, & Macdonald, 2023). Although there is no standard definition of RA, key principles are embodied in practices such as agroforestry, cover cropping, rotational farming, reduced tillage, mulching, push-pull technology, permaculture, nutrient cycling, and organic agriculture, all aimed at restoring soil quality, increasing biodiversity, and improving productivity (AGRA & IIRR, 2021; Giller et al., 2021; Goswami et al., 2021; Jayasinghe et al., 2023). These practices further aim to minimize soil disturbance, control weeds and pests, conserve soil moisture, reduce agrochemical use, manage farm wastes, optimize resource use, control soil erosion, provide animal feeds, reduce greenhouse gas (GHG) emissions and production costs, and enhance nutrient cycling (Elevitch, Mazaroli, & Ragone, 2018; Iqbal et al., 2020; Jayasinghe et al., 2023).

Regenerative agriculture is considered effective in mixed farming systems, which are practiced by the majority of smallholder farmers. As farmers integrate livestock into crop production, the system creates synergies that enhance soil organic matter, reduce the need for external farm inputs, and lower production costs (Çakmakçı et al., 2023; Giller et al., 2021; Kremen, Iles, & Bacon, 2012). Furthermore, low external input enhances the production of chemical-free products catering to consumer demand for nutritious and organic food (Hendrickson, Hanson, Tanaka, & Sassenrath, 2008; Mosnier, Benoit, Minviel, & Veysset, 2022). Regenerative agriculture is further enhanced in mixed farming through fodder production, which improves soil fertility and serves as animal feed, the production of legumes, and managed grazing systems. The philosophy of RA aims at promoting a quality of life through both the monetary value of the farming system and agroecological gains (Giller et al., 2021; Rodale, 1983).

Kenya presents strong evidence of organizations supporting RA. These include the Kenya Organic Agriculture Network, Alliance for a Green Revolution, Farm Africa, Participatory Ecological Land Use Management, Climate-

Smart Agriculture, National Sector Development Strategy, International Institute of Rural Reconstruction, Innovation for Poverty Action, and the National Climate Change Response Strategy, among others (Food and Agriculture Organization of the United Nations (FAO), 2019; Ntawuhiganayo, Nijman-Ross, Geme, Negesa, & Nahimana, 2023).

However, there is still an insignificant contribution to the global regenerative agricultural product market. Therefore, it is crucial to accelerate adoption by gaining a deeper understanding of RA and how it is operationalized within a mixed farm setting. This will lead to attaining sustainability in mixed farming systems that dominate the Kenyan farming system. This can contribute to expanding the regional regenerative agriculture market share globally. The study, therefore, aimed to characterize the regenerative agricultural practices in the mixed farming systems and evaluate the drivers of regenerative agriculture adoption in the mixed farming systems in Kenya.

2. MATERIAL AND METHODS

2.1. The Study Area

This study was conducted in Trans-Nzoia and Uasin Gishu counties in Kenya. The counties significantly contribute to food production, especially dairy and cereals. These areas benefit from conducive agroecological conditions, with fertile arable land and adequate annual rainfall during the long and short rainy seasons, which support agricultural activities (Kisaka et al., 2015). The soils in the Trans-Nzoia are moderate to deep red and brown clay, black cotton, and sandy clay soils of medium to high fertility, consisting of acrisols, cambisols, and their combinations. These soils are extensively weathered and leached, exhibiting iron and aluminium oxides accumulation. Temperatures in Trans Nzoia range from a minimum of 14°C to 18°C to a maximum of 30°C to 36°C, and average rainfall ranges from 1740 mm to 1940 mm (County Government of Trans Nzoia, 2023). In Uasin Gishu, the soils are a mixture of shallow/low and deep/highly fertile soils, consisting of andosols, arenosols, cambisols, ferralsols, fluvisols, and luvisols as the main soil types. The temperatures range from a minimum of 10°C to 14°C and a maximum of 22°C to 28°C, and the average rainfall varies from a minimum of 950mm to 3000mm (Government of Kenya (GoK), 2019).

The main economic activities in the counties were crop cultivation and livestock production. The predominant integrated farming systems are dairy-maize farming, dairy-wheat, and dairy-vegetable farming systems (Van Der Lee, Bebe, & Oosting, 2016). However, other crops, including beans, bananas, rice, vegetables, fruits, sorghum, cassava, sweet potatoes, and millet, are produced for subsistence. Farmers also produce cash crop products such as sugarcane, soybean, cotton, and pyrethrum on a small to medium scale. Livestock farming is also prevalent, with many households raising cattle, sheep, goats, donkeys, and poultry. Aquaculture activities are conducted on a smaller scale (County Government of Trans Nzoia, 2023; County Government of Uasin Gishu, 2022).

2.2. Research Design and Data Collection

Primary data was collected through a cross-sectional survey using a semi-structured questionnaire digitized into Kobo Collect software and administered to mixed smallholder farmers. The questionnaire inquired about the types of crops and livestock kept, information on regenerative agricultural practices, their characteristics, drivers of adoption, benefits, and challenges experienced during implementation. A multistage sampling technique was employed for data collection. Trans-Nzoia and Uasin Gishu counties were purposively selected for the study, as they are part of the Kenyan food basket region. A list of dairy producers was obtained from the National Dairy Breeders' Registry (Kenya Studbook) at the Kenya Livestock Breeders Association. A random sampling method was used to identify potential respondents from the list, with assistance from county agricultural officers in the study area. Subsequently, trained enumerators systematically selected respondents from the list of farmers provided. Prior to the main survey, a pilot study was conducted in Elgeyo Marakwet County, which exhibits similar farming practices and climate to the study areas. A total of 460 questionnaires were administered to mixed dairy cattle cereal farmers. Of these, 397 questionnaires contained complete information and were used for analysis using STATA software.

2.3. Validity of the Questionnaire

The validity of the research instruments was tested by experts. The consultation was in the initial stages with the supervisors and researchers in agricultural economics on the validity and the ability of the questionnaire to collect data that will address the objectives of the study. This process was largely a face validity process in discussions. The essence was to ensure content validity. Throughout the process, some questions were validated for inclusion, some were adjusted, and ambiguous and confusing questions were deleted from the questionnaire.

2.4. Data Analysis

This study evaluated farming practices aligned with RAPs identified in the literature. Descriptive statistics were used to categorize the practices based on their ability to enhance soil fertility, nutrient cycling, and livestock feed production, reduce land degradation, manage pests and weeds, and optimize resources. The implementation strategy, reasons for adoption, and challenges experienced for each practice were also assessed. Each practice was further evaluated based on the time of practice and the farms that adopted them. The number of farms practicing each RAP was used to categorize the RAP adoption level. Practices on less than a third of the farms, representing fewer than 132 farms, were classified as low adoption; those adopted by between a third and two-thirds of farms, representing between 132 and 264 farms, were considered moderate adoption; and practices adopted by more than two-thirds of farms, representing over 264 farms, were identified as high adoption of RAPs. Furthermore, farms with fewer than 6 RAPs, representing a third of the RAPs assessed, were classified as low adoption; those with 7-12 RAPs, representing up to two-thirds of the RAPs, were considered moderate adoption; and farms with more than 13 RAPs, representing over two-thirds of the RAPs, were classified as high adoption. A binary logistic regression model was used to evaluate the drivers of the RA adoption level. The logistic regression model used is presented in Equation 1.

$$Q = \beta_0 + \sum_{j=1}^{n} \beta_j X_{ji} + \varepsilon i \quad (1)$$

Table 1. Model description of variables used in evaluating the drivers of RAPs adoption.

Objective	Variable	Description	Measurement	Sign.
	Dependent variable			
	Q= is the adoption level	The adoption level of RAPs based on 18 RAPs	Dummy:0= Low; 1=Moderate	
	Independent variables			
	X_1 Training	If a farmer has been trained on any RAP.	Dummy:1=trained; 2=not trained	+
Drivers of RAP adoption	X_2 Attitude toward RA	The attitude of the farmer towards RAPs.	Ordinal: 1=Very positive;2= positive;3=neutral; 4=negative;5= very negative	+
	X_3 Benefits level of RA	The benefits a farmer gets from the RAPs.	Ordinal: 1=Very high;2=High;3=Medium;4=Low;5= Very low	+
	X_4 Conflict level	The level of conflicts with other farming systems	Ordinal: 1=Very high;2=High;3=Medium;4=Low; 5=Very low	+/-
	X_5 Types of crops	The types of crops produced on a farm.	Dummy: 1=Food crops alone; 2= otherwise (Food crops + Cash crops)	+
	X_6 Land terrain	The terrain of the cultivated farm	Dummy: 1=Flat terrain; 2= otherwise (Hilly, Valley, Swampy)	+/-
	X_7 Farm size	The size of the farm cultivated	Continuous: Acres of land	+/-
	X_8 Land ownership	If the farmer owns the cultivated land.	Dummy: 1=land owned; 2=land rented	+
	X_9 Farm fertility status	The fertility of the cultivated farm	Ordinal: 1=Very good; 2= good; 3=moderately good; 4=moderately poor; 5=very poor	+

Objective	Variable	Description	Measurement	Sign.
	X_{10}Subsidy program beneficiary	If the farmer is a beneficiary of the farm inputs subsidy program.	Dummy: 1=Beneficiary;2= non-beneficiary	+/-
	X_{11}Access to the synthetic inputs market	If the farmer has access to the agro-dealers selling farm inputs.	Ordinal: 1=Very difficult; 2=Difficult; 3=Easy; 4=Very easy	-
	X_{12}Location/County	The county where the farm is located	Dummy: 1=Trans Nzoia; 2=Uasin Gishu	+/-

Where Q= is the adoption level of RAPs based on 18 RAPs; (low or moderate), β_0 is the intercept, j=1, 2, 3… n, where n is the number of regressors (X_1 Farmers training, X_2 Farmer attitude on RA, X_3 Benefits level of RA, X_4 Conflict level with convention farming systems, X_5 Types of crops, X_6 Land terrain, X_7 Farm size, X_8 Land ownership status, X_9 Farm fertility status, X_{10} Subsidy program beneficiary, X_{11} Access to synthetic inputs market, X_{12} Location/county, β_j are slope coefficients of the regressors, X_{ji} are the explanatory variables for the i^{th} observation, i =*1*, *2*, *3…397* are observations on variables for the model, ε_i is the standard error term for the i^{th} observation. Table 1 describes the variables used in the model in Equation 1.

Table 2. Characterization of regenerative agricultural practices in mixed farming systems.

RAPs identified	Agroecological principles	Supporting regenerative agricultural practice	Prevalence	%	Priority weight
1. Intercropping 2. Fodder production 3. Rotational/ Managed grazing 4. Feeding animals on crop residue 5. Crop residue retained on farms 6. Composting crop residue 7. Crop rotation 8. Mulching using crop residue 9. Composting animal wastes 10. Zero-tillage 11. Agroforestry 12. Diversification of species 13. Organic farming 14. Planting legumes 15. Water harvesting/ irrigation 16. Terracing 17. Ridges on the farm 18. Integrated pest management	Enhancing soil fertility	Crop residue retained on farms; Crop rotation; Mulching using crop residue; Composting animal wastes; Zero-tillage; Agroforestry; Diversification of species; Organic farming; Planting legumes; Fodder production; Intercropping; Rotational/ Managed grazing;	13/18	72	0.21
	Enhancing nutrient cycling/Minimum external inputs	Feeding animals on crop residue; Crop residue retained on farms; Mulching using crop residue; Composting animal wastes; Zero-tillage; Agroforestry; Diversification of species; Organic farming; Planting legumes; Fodder production; Intercropping; Crop rotation; Rotational/ Managed grazing	13/18	72	0.21
	Production of livestock feeds	Fodder production; Feeding animals on crop residue; Agroforestry; Rotational/ Managed grazing;	4/18	22	0.07
	Optimization of resources	Intercropping; Agroforestry; Diversification of species; Water harvesting/ Irrigation; Rotational/ Managed grazing; Organic farming; Planting legumes; Integrated pest management; Composting animal wastes; Feeding animals on crop residue; Fodder production	11/18	61	0.18
	Reducing land degradation	Rotational/ Managed grazing; Crop rotation; Zero-tillage; Agroforestry; Diversification of species; Organic farming; Planting legumes; Terracing; Ridges on farm; Integrated pest management; Fodder production;	11/18	61	0.18
	Managing pests, disease, and weeds	Crop rotation; Mulching using crop residue; Organic farming; Zero-tillage; Diversification of species; Planting legumes; Intercropping; Integrated pest management	9/18	50	0.15

3. RESULTS

3.1. Characterization of Regenerative Agricultural Practices in Mixed Farming Systems

3.1.1. Classification of Regenerative Agricultural Practices According to Agroecological Principles

Table 2 presents 18 regenerative agricultural practices identified in the study area. The RAPs are further categorized according to agroecological necessity for adoption. The priority of regenerative agriculture adoption was to enhance soil fertility and nutrient cycling, with a weight of 0.21 for each, representing 13 RAPs. In order of priority, they are followed by the intent to reduce land degradation and optimize resource usage, each with weights of 0.18, representing 11 RAPs. Managing pests, diseases, and weeds has a weight of 0.15, representing 9 RAPs. The lowest weight of 0.07 is associated with the production of livestock feeds, representing 4 RAPs.

Prevalence is the proportion of the RAPS supporting each agroecological principle, and Priority Weight is the proportion of percentage prevalence for each agroecological principle.

3.1.2. Implementation of Regenerative Agricultural Practices in Mixed Farming Systems

Table 3 shows the different modes of applying RAPs in mixed farms. Mixed, row, strip, or relay intercropping systems were used. The systems included planting the intercrop in defined rows, scattered on a farm with the main crop, on the hedge of the rows, combining tall and short crops, on the boundaries, and concurrently in the same rows. The intercropping system included cereal-legume, cereal-legume-fodder, cereal-legume-vegetable, cereal-legume-banana-vegetables, and cereal-legume-banana-vegetables-sugarcane.

Livestock management was conducted through managed open grazing, semi-zero/zero grazing, paddocking, and tethering. The free-range farming, yarding, and cage systems were used in poultry production. In the cropping system, 41.56% of the farms integrated cows alone; 24.18% integrated poultry and cows; 10.58% integrated poultry, cows, and sheep; 3.53% integrated cows and goats; 8.56% integrated cows and sheep; and 0.25% integrated poultry, cows, sheep, goats, fish, and bee farming.

The dominant feeding systems for the cows were semi-zero grazing at 26.95%, open managed grazing at 26.7%, paddocking at 25.19%, zero grazing at 13.85%, and managed tethering at 7.05%. Goat farming was practiced on 54 farms, with 61.11% using open managed grazing, 27.78% practicing tethering, and 11.11% practicing semi-zero grazing. Sheep were reared on 98 farms, with feeding systems including open grazing at 24.49%, tethering at 61.22%, and semi-zero grazing at 14.28%. In poultry, involving 166 farms, 54.76% practiced a free-range system, 35.12% used yarding systems, and 8.93% used cages.

Fodder was planted in separate plots, along the farm boundaries, ridges, edges of rows, and terraces, as an intercrop, and under push-pull technology. The dominant fodder was Napier grass at 60.5% of the farms, desmodium at 11.8%, brachiaria at 10.3%, bomar hodes at 9.3%, and lucerne at 1.8%.

Beans, maize, and vegetables had the highest rotation intensity on farms. Farm composting was conducted using animal wastes and crop residues. The animal wastes included manure from cows, sheep, goats, and poultry. The residues used in composting consisted of cereal crop stubble, legumes, and remains of animal feeds.

Agroforestry was implemented by planting trees on the boundaries of the crop farm, around the farm, in rows within the farm, scattered throughout the farm, in separate plots, along terraces within the farm, and on the hedges of crop rows. 62.15% of the farms had eucalyptus trees, 55.39% had Cyprus trees, 44.22% had grevillea trees, 43.03% had avocado trees, and 40.64% had mango trees. Other species included Pinus, crotons, Sesbania, guava, citrus, Elgon tick, and acacia, among others. There was a total of 28 different species of trees on the farms.

In diversifying, farms engaged in production, processing, value addition, marketing, selling, and transportation. Farms produced at least three crop species, with the highest being 10. Maize and beans were cultivated on most farms. Farms produced at least one livestock species, with the highest being six. Only cows were kept on 51.56% of the farms; cows and poultry on 24.18%; cows, poultry, and sheep on 3.27%; and cows, poultry, sheep, goats, fish, and bees on just 0.25% of the farms. The breeds of cows included 47.61% crossbreed, 30.73% exotic, and 12.85% indigenous.

Farms with both crossbreed and indigenous breeds were 2.01%; exotic and indigenous breeds were 0.25%; and breeds that included exotic, crossbreed, and indigenous were found on just 0.25% of the farms. The poultry system was dominated by chickens on 38.54% of the farms; chicken-duck on 1.5%; chicken-turkey on 0.25%; duck-turkey on 0.25%; and turkey alone was found on 0.25% of the farms.

Table 3. The modes of regenerative agricultural practices application in mixed farming and the products involved.

	The mode of application	Farm products involved
1	Different crops on straight lines in separate rows (51.7%); different crops scattered on the farm (28.6%); intercrops on the hedge of the rows (12.1%); tall and shorter plants (11%); intercrops on the boundaries (16%); concurrently in the same rows (13.2%)	Cereal-legume (72.04%), cereal-legume-fodder (66.4%), cereal-legume-vegetable (26%); cereal-legume-Banana-vegetables (24.3%), cereal-legume-Banana-vegetables-sugarcane (8.2%)
2	Separate plots (82.5%); along farm boundaries (20.23%); terraces (17.51%); on the same plot with crops including under push-pull technology (16.34%); along the ridges and hedgerows of the farms (10.89%)	Napier grass (60.5%); *Desmodium* (11.8%); *Brachiaria* (10.3%); *Boma Rhodes* (9.3%); *Lucerne* (1.8%); Stover (100%)
3	Semi-zero grazing (26.95%); Open managed grazing (26.7%); Paddocking (25.19%); Zero grazing (13.85%); Managed tethering (7.05%)-*which cows*	Cows (51.56%); cows-poultry (24.18%); cows-poultry-sheep (10.58%); cows-poultry-goats (3.27%); cows-sheep (8.56%); cows-poultry-sheep-goats-fish-bee (0.25%). Cows system: Crossbreed (47.61%); Exotic (30.73%); Indigenous (12.85%); crossbreed-exotic (4.79%); crossbreed-Indigenous (2.01%); exotic-Indigenous (0.25%); exotic-crossbreed-Indigenous (0.25%); Poultry system: Chicken (38.54%); chicken-duck (1.5%); chicken-turkey (0.25%); chicken-duck-turkey (0.25%); Turkey (0.25%);
	Semi-zero grazing (11.11%); Open managed grazing (61.11%); Managed tethering (27.78%)	
	Semi-zero grazing (14.28%); Open managed grazing (24.49%); Managed tethering (61.22%)	
	Free-range system (54.76%); yarding system (35.12%); cages (8.93%)	
4	Crop residue is stored to feed livestock after harvesting crops.	Crop residue used: Stover; vines; sugarcane cuttings; legume residue
5	Crop residue is left to decompose on the farm	Cereal crops; vines; sugarcane cuttings; stover
6	Planting legumes, root crops; and vegetables after harvesting cereal crops.	
7	Using crop residue and tree branches to cover the soil	Cereal crop residues; sugarcane cutting; fodder remains
8	Preparation of farm-yard, composite, and green manure as organic fertilizer	Animal manure; kitchen wastes; fodder leftovers; crop residues
9	Plowing the farm once before planting; direct seeding in crop residues.	
10	Trees are planted along boundaries, within crop fields (rows or scattered), and on separate plots inside the farm.	eucalyptus (62.15%); Cyprus (55.39%); grevilia (44.22%); avocado (43.03%); mango (40.64%), Pinus, crotons, Sesbania, guava, citrus, elgon tick, acacia
11	Crop species; animal species; Fodder; types of tree; diversity in farm activities	Crops; livestock; trees; fodder; farm operations
12	Use manure; rotational grazing; crop residue; organic inputs	Cow manure; poultry manure; goats manure; sheep manure
13	Planting as intercrops and cover crops	Beans; sunflower; cowpea; fodder; desmodium; lucern
14	Harvesting rainwater, water from streams	
15	Crop rotation (33.2%); intercropping (45.9%); push-pull technology (5.79%)	Fodder crops: *Desmodium*; *Brachiaria*

Note: Practices: Intercropping[1]; Fodder production[2]; Rotational/ managed grazing (cows), (goats), (sheep) (poultry) farming system[3]; Feeding animals on crop residue[4]; Crop residue retention[5]; Crop rotation[6]; Mulching[7]; Composting[8]; Zero-tillage[9]; Agroforestry[10]; Diversification of species[11]; Organic farming[12]; Planting legumes[13]; Water harvesting/ irrigation[14]; Integrated pest management[15].

3.1.3. Reasons for Adopting Regenerative Agriculture in the Mixed Farming System

Table 4 presents the reasons for adopting RAPs in order of prevalence across the farms. The primary reasons were to enhance soil fertility and to improve farm productivity. Other reasons included increasing farm income, promoting nutrient cycling, diversifying farm products/conserving soil, lowering production costs, minimizing the use of agrochemicals, controlling soil erosion, mitigating climate change, generating livestock feed, conserving soil moisture, enhancing land utilization, providing shade/support for other farm products, controlling weeds, and managing pests.

3.1.4. The Challenges in Adopting Regenerative Agriculture in Mixed Farming Systems

The challenges that farms face in practicing RA, listed in order of dominance, are presented in Table 5. Small land sizes and high labor intensity were the most prominent challenges. Other challenges included the high cost of labor, inadequate inputs for farmers, the effects of climate change, pressure to produce staple food, difficulties in mechanizing some of the RAPs on a farm, time-consuming processes, challenges in operationalizing RAPs on a large scale, incompatibility of the crops, reduced crop productivity, low-quality fodder, easy disease spread, pest problems, hardships in harvesting, inadequate skills among farmers, effects on soil fertility, a lack of markets for output, and insufficient information.

3.1.5. Adoption of Regenerative Agricultural Practices in Mixed Farming Systems

Table 6 outlines the adoption rates of each RAP assessed in mixed farms, the years during which the farms have participated in the practice, and the adoption level for each practice. Fodder production, managed grazing, feeding livestock on crop residue, diversification of plant and animal species on farms, and legume production were highly adopted. Intercropping, retaining crop residue on the farm to decompose, crop rotation, and agroforestry were moderately adopted. Composting animal wastes and crop residue, mulching, zero-tillage, organic farming, water harvesting/irrigation, terracing, ridge construction, and integrated pest management had a low adoption.

Table 4. Reasons for adopting regenerative agriculture in the mixed farming system.

Reason	*Regenerative agricultural practices*														p	15
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**		
Improve soil fertility	116	13	105	17	69	15	39	230	202	3		38	197	138	49.76	1
Improve production	91	200	79	9	57		37	135		3	17	28	201	285	48.08	2
Increase farm income	59	8			12			321					103	290	33.38	3
Recommended practice	73	9	60	11	43			250	117	5	12	20	39	23	27.87	4
Nutrient cycling					67			166	105					196	22.48	5
Diversity/ Conservation	91		4			75		194	2		24		102		20.71	6
Reduce production cost	18		16		35		48	119	190		2	19			18.82	7
Reduce agrochemicals	17		17	7	47		29	57				46		210	18.10	8
Control soil erosion	11	20	8	16	6	44	31	96	12	47	2	8	68	56	17.89	9
Mitigate climate change	30			7			10	130		14	39	40			11.36	10
Livestock feeds		250				12									11.03	11
Conserve soil moisture				15			34	79	6	49	27		46		10.77	12
Better land utilization	*122*							*56*	*1*		*28*				8.71	14
Provide shade/ Support	7			12		118									5.76	15
Control weeds	12	2	29	11	2			16				8			3.36	16
Boundary		23				4				53					3.36	17
Control pests	6	3	27	4		2		10			1	4			2.4	18
Adoption frequency (x/ 397)	182	264	132	27	79	251	59	397	227	69	59	60	287	282		

Note: Intercropping1; Fodder production2; crop rotation3; mulching4; composting5; agroforestry6; zero/minimum tillage7; diversification8; crop residue retained9; terracing10; water harvesting and irrigation11; organic farming12; planting legumes13; rotational grazing14; Order prevalence 15; prevalence p.

Table 5. Challenges in adopting regenerative agriculture in mixed farming systems.

Challenge	Regenerative agricultural practices														P	15
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**		
Small pieces of land		138				87		250	221	26			70	201	41.81	1
High labor intensity	60	22		10	30			259	213	5	8	56		9	28.29	2
Costly labor	41				17				192		4			169	17.81	3
Inadequate inputs		64	68					240							15.66	4
Affected by climate change		106	2		14								170	45	14.18	5
Pressure for staple food			73			102		160							14.1	6
Challenge to mechanize	46	31				32		131		30					11.36	7
Time-consuming			32		58	155	12					34			12.25	8
Challenge on a large scale				18	48				195						10.98	9
Incompatibility	31	98	5			70							53		10.82	10
Lowers crop productivity	46				2	140	6					45			10.06	11
Low-quality fodder		50												149	8.37	12

Challenge	Regenerative agricultural practices														P	15
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
Easy disease spread	53			9			2	120							7.74	13
Diseases and pests	23	79							34			45			7.62	14
Harvesting challenge	82					51		40							7.28	15
Inadequate skill	10		21				44	42							4.92	16
Affect soil fertility						102				9					4.67	17
No market for output		5				9		47							2.56	18
Inadequate Information				3			6	8							0.71	19
Adoption frequency (x/ 397)	182	264	132	27	79	251	59	397	227	69	59	60	287	282		

Note: Intercropping1; fodder production2; crop rotation3; mulching4; composting5; agroforestry6; zero/minimum tillage7; diversification8; crop residue retained9; terracing10; water harvesting and irrigation11; organic farming12; planting legumes13; rotational grazing14; order prevalence15; prevalence[P].

Table 6. Regenerative agricultural practices adoption in mixed farming systems.

Regenerative Agricultural Practice	Adoption frequency in Trans Nzoia (n=176)	Adoption frequency in Uasin Gishu (n=221)	Total adoption frequency (n=397)	Adoption percentage (%/100)	Years of experience in the RAPs	Adoption level: Low (< 132 farms or 33%), Moderate (>132<264 farms or 34%-66%), High >264 farms or 66%
Intercropping	82	100	182	45.9	15.9	Moderate
Fodder production	102	162	264	66.5	8.67	High
Rotational/ managed grazing	128	163	291	73.30	15.3	High
Feeding animals on crop residue	170	212	382	96.2	14.2	High
Crop residue retained on farms	85	142	227	57.2	16.5	Moderate
Composting crop residue	15	16	31	7.81	10.0	Low
Crop rotation	32	100	132	33.2	7.75	Moderate
Mulching using crop residue	15	12	27	6.80	3.48	Low
Composting animal wastes	38	41	79	19.9	10.1	Low
Zero-tillage	22	37	59	14.9	3.84	Low
Agroforestry	121	130	251	63.2	12.5	Moderate
Diversification of species	176	221	397	100.	10.2	High
Organic farming	33	27	60	15.1	7.90	Low
Planting legumes	123	164	287	72.3	13.3	High
Water harvesting/ Irrigation	41	18	59	14.9	9.46	Low
Terracing	46	23	69	17.4	8.88	Low
Ridges on the farm	6	8	14	3.52	5.14	Low
Integrated pest management	10	13	27	6.80	7.80	Low

3.1.6. Adoption Levels of Regenerative Agriculture in Mixed Farms

Figure 1 the text presents the adoption level of RA; 157 farms had low adoption, 238 had moderate adoption, and only two had high adoption.

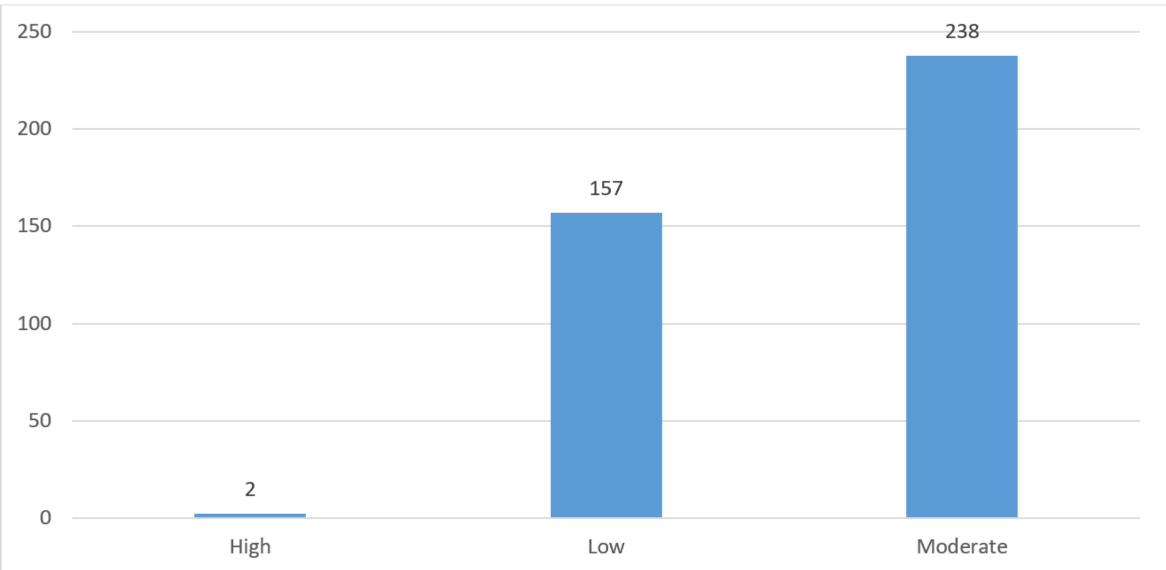

Figure 1. Adoption level of regenerative agricultural practices in mixed farms.

3.1.7. The Drivers of Regenerative Agriculture Adoption in Mixed Farms

Drivers of RA are presented in Table 7. The significant variables at a 95% confidence interval were farmers' training, farmers' attitude toward RA, the benefits level of RA, the types of crops, land ownership status, and the subsidy program beneficiary.

Training on RA increased the odds of becoming a moderate adopter of RAPs (versus a low adopter) by 2.29 times. Positive attitudes towards RAPs increased the odds of becoming a moderate adopter of RAPs by 0.779 times. Having experienced high benefits from RAPs increased the odds of becoming a moderate adopter of RAPs by 1.413 times. A farm producing food crops alone increased the odds of becoming a moderate adopter of RAPs by 1.26 times compared to farmers producing cash crops. Owning land increased the odds of becoming a moderate adopter of RAPs by 6.845 times compared to farmers renting. Benefiting from a subsidy program increased the odds of becoming a moderate adopter of RAPs by 1.883.

Table 7. The odds ratio results for the drivers of regenerative agricultural practices adoption in mixed farms.

Low adoption =1-6 RAPs (157 farms), moderate adoption = 7-12 RAPs (238 farms)	Odds ratio	St. Err.	Z	p>/z/	[95% Con. Interval]		Sig.
Farmer training	2.29	0.560	3.38	0.001	1.41	3.69	***
Farmer's attitude toward RA	0.779	0.074	2.62	0.009	0.647	0.939	***
Benefits level of RA	1.41	0.139	3.51	000	1.16	1.72	***
Conflict level/ Incompatibility with other sustainable farming systems	1.16	0.099	-1.74	0.081	0.982	1.37	
Types of crops	1.26	0.095	3.07	0.002	1.08	1.46	***
Land terrain	1.03	0.215	0.15	0.882	0.686	1.55	
Farm size	1.03	0.020	1.65	0.100	0.994	1.07	
Land ownership status	6.84	5.22	2.52	0.012	1.53	30.5	**
Farm fertility status	1.03	0.020	1.69	0.091	0.995	1.07	
Subsidy program beneficiary	1.88	0.526	2.27	0.023	1.09	3.26	**
Access to the synthetic inputs market	1.31	0.297	1.19	0.233	0.840	2.04	
Farm location/County of residence	0.777	0.204	-0.96	0.337	0.465	1.30	
Constant	0.000	0.000	-5.43	0.000	0.000	0.002	***
Mean dependent var	0.856	SD dependent var		0.990			
Pseudo r-squared	0.543	Number of obs.		397			
Chi-square	100.449	Prob > chi2		0.000			

Note: *** P<0.01, ** P<0.05.

4. DISCUSSION

4.1. Characterization of Regenerative Agricultural Practices

4.1.1. Classification of Regenerative Agricultural Practices

The RAPs were crucial to enhancing soil fertility. Farm practices such as leaving crop residues to decompose on the farm enhanced soil fertility by increasing soil carbon. Crop rotation allowed the soil to regenerate its fertility, especially when the crops belonged to different families. Since crops utilized different nutrients, rotation replenished soil fertility. Some crops included in the rotation cycle, such as fodder and legumes, also fixed nitrogen in the soil. When mulching material decomposed, soil fertility increased. Composting livestock manure, organic household waste, and crop residues into organic fertilizer boosts soil fertility. Zero-tillage facilitated carbon accumulation, promoted soil biodiversity, and encouraged the existence of microorganisms to enhance the breakdown of soil organic matter, further increasing fertility. Agroforestry enhanced carbon sequestration, which raised soil carbon levels. Diversification and intercropping enabled the soil to regenerate through the interaction of various plants within it. Rotational grazing encouraged the soil to replenish fertility and control land degradation. These results are consistent with the literature (Giller et al., 2021; Khangura, Ferris, Wagg, & Bowyer, 2023; Schreefel, Schulte, De Boer, Schrijver, & Van Zanten, 2020; Tindwa, Semu, & Singh, 2024). These studies have advocated for RAPs to enhance soil fertility.

The RAPs were crucial to enhancing nutrient cycling. This was associated with feeding livestock on crop residue to improve animal productivity, retaining crop residue to decompose on a farm, composting livestock wastes, and using crop residue to prepare composite manure or organic fertilizer. Mulch allowed to decompose on a farm, carbon sequestration in agroforestry, maintaining soil carbon with zero-tillage, planting legumes and fodder to fix nitrogen in the soil, intercropping to allow crop interaction, and rotating crops on the farm to promote regeneration of nutrients and enhance soil fertility through nutrient cycling. This reduced the need for external farm inputs, such as inorganic fertilizers. This aligns with the studies in the literature (Jayasinghe et al., 2023; Kangogo, Dentoni, & Bijman, 2021; Teague & Kreuter, 2020). According to the studies, nutrient cycling is a crucial component of regenerative agriculture.

Regenerative agricultural practices are crucial in producing livestock feed. Fodder and crop residue are used as animal feed or to prepare silage and hay. Some of the trees in agroforestry are used to generate animal feed. Managed grazing allows an effective feeding system that enables livestock to feed optimally through a controlled system. This concurs with the literature on RA (Jayasinghe et al., 2023; Ntawuhiganayo et al., 2023).

Regenerative agricultural practices optimize the use of farm resources. This approach is linked to utilizing resources such as land and other available inputs, including co-products produced. It includes using farm resources to feed livestock, produce organic manure, and promote nutrient cycling techniques. Several studies in the literature have reported similar findings (Burgess, Cano, & Parkes, 2022; Giller et al., 2021; IFOAM – Organics International, 2023; Schreefel et al., 2020). According to the studies, RA is a sustainable intensification strategy.

Regenerative agricultural practices have reduced land degradation. This involved rotational grazing to reduce overgrazing, zero tillage to preserve soil structure, planting trees to combat soil erosion on the farm, crop rotation to minimize fertility depletion, and cultivating fodder and legumes as cover crops to safeguard the soil. These results align with the existing literature (AGRA & IIRR, 2021; Giller et al., 2021; Jayasinghe et al., 2023).

Regenerative agriculture was also crucial to managing pests and weeds. Farmers used crop rotation, zero-tillage, diversification of species, and intercropping to suppress and break the pests' lifecycle. They applied mulching to suppress weed growth and incorporated fodder in push-pull technology to control both pests and weeds. The results align with the literature (Hagelberg, Wikström, Mattila, & Joona, 2020; Lebrazi & Fikri-Benbrahim, 2022; Novikova, 2014; Rana, 2016).

4.1.2. Implementation of Regenerative Agricultural Practices in Mixed Farming Systems

Intercrop systems allow the interaction of crops to facilitate optimal nutrient cycling, groundwater utilization, and soil nutrient replenishment. Through biological nitrogen fixation, legumes and fodder intercrops benefit the main crops, such as cereal crops. This approach helps maintain soil fertility and reduces the need for external inputs. Intercropped systems promote agro-biodiversity, which enhances soil protection and fertility restoration. These results are consistent with the literature on regenerative agriculture (Frac, Kowalska, Nowak, & Zieliński, 2023; Maitra et al., 2021; Mazzafera, Favarin, & Andrade, 2021; Mousavi & Eskandari, 2011). The literature underscores the necessity of good crop selection and an interactive intercropping system as a regenerative practice.

The livestock integrated into rotational systems allowed the interaction of animals with nature, thereby enhancing the synergistic production system. Managed grazing systems promoted the restoration of the ecosystem and nutrient cycling among its components. Paddocking enabled farms to regulate grazing patterns, thereby regenerating soil fertility. In this system, livestock were fed on grass and plant materials, and the soil benefited from animal wastes. The results are consistent with previous literature (Çakmakçı et al., 2023; Danso-Abbeam et al., 2021; Giller et al., 2021; Teague & Kreuter, 2020). Therefore, the implementation of livestock integration is crucial for regenerating soil fertility.

Fodder production was a crucial soil fertility regenerator practice. Some fodder, such as desmodium, adds additional nutrients to the soil, suppresses weeds on a farm, repels insects from the main crop, attracts pests from the crops, and increases soil moisture. This reduces the need for external chemicals on a farm to control pests, weeds, and nitrogenous fertilizers. Fodder planted along the terraces and farm boundaries also controls soil erosion to maintain fertility. Fodder increased farm biodiversity and, as a cover crop, during the off-season in systems such as push-pull technology to ensure the maintenance of living roots in the soil around the year. These results align with the literature (Ayuko, Ochieng, & Mwangi, 2024; Drinkwater, Midega, Awuor, Nyagol, & Khan, 2021; Dumont et al., 2020; Kebede, 2024; Rana, 2016; Schreefel et al., 2022). The literature emphasizes the need to produce fodder on the farm for socio-economic benefits.

Crop rotation enhances soil fertility, maximizes soil water and nutrients, and controls the spread of weeds, pests, and diseases without any external inputs. The high rotation in crops such as beans is associated with the crops' vital role in achieving food security, the short maturity period, and the source of household income. The results agree with the literature (Galindo et al., 2020; Giller et al., 2021; Iheshiulo, Nwankwo, & Chukwu, 2023; Sahu & Das, 2020). However, a good rotation system may also need to incorporate livestock to enhance nutrient regeneration.

Composting organic fertilizer enhances soil fertility. This is achieved by including animal wastes and crop residues in a composite to contain all the necessary nutrients. This process promotes nutrient cycling from plants and animal wastes to improve soil fertility. It also reduces the need for chemical fertilizers in the soil, optimizing the activities of soil microorganisms required for soil fertility restoration. Therefore, a good combination of quality materials results in high-quality organic manure. The results align with previous studies (Amrul et al., 2022; Anyega et al., 2021; McClelland, Johnson, & Smith, 2022; Voisin, Thompson, & Rivera, 2024).

Planting trees on farms was associated with increased carbon sequestration, reduced soil erosion, provided support and shade to the crops, increased biodiversity and ecological resilience of the ecosystem, maintained soil moisture, improved soil fertility, and increased organic matter. Trees attract pollinators, which increase the farm's biodiversity, attract rainfall necessary for crop production, and the deep roots of trees make soil nutrients available for crops. Trees also ensure that the living roots are maintained in the soil. Some trees repel pests from the crops and prevent soil erosion, affecting soil fertility. The results are consistent with the literature (Coulibaly, Kuntashula, & Mungatana, 2017; Ghimire, Khanal, Bhatt, Dahal, & Giri, 2024; Lebrazi & Fikri-Benbrahim, 2022; Rana, 2016). However, for agroforestry to succeed, there should be a variation in the species.

Diversifying a farm by integrating crops, livestock, fodder, and trees plays a crucial role in restoring and maintaining soil fertility. This biophysical interaction facilitates natural nutrient recycling processes, reducing dependence on external inputs. For instance, manure produced by livestock enriches crop fields with essential nutrients, while animals feed on both fodder and crop residues, creating a closed-loop system (Schreefel et al., 2022; Schreefel et al., 2020). Fodder crops not only serve as feed but also contribute to soil health by fixing nitrogen, thereby enhancing nutrient availability. Additionally, agroforestry practices add organic carbon to the soil, improving its structure and long-term fertility (Liu et al., 2022; Sahu & Das, 2020). These synergistic relationships demonstrate that on-farm diversity is not only a sustainable practice but also a viable strategy for enhancing soil fertility through ecological means.

4.1.3. Reasons for Adopting Regenerative Agriculture in the Mixed Farming Systems

Regenerative agriculture has been adopted as a sustainable production strategy. The RAPs were implemented as solutions to declining soil fertility and interventions for land degradation resulting from conventional farming systems. Therefore, the entry point of RA in production was to improve soil fertility. Different RAPs enhance soil fertility through carbon sequestration and nitrogen fixation to boost farm productivity.

Increased farm income was attained through low use of external inputs such as chemicals, commercial animal feeds, and inorganic fertilizers. Organically certified products attracted a higher market premium for organic products. Furthermore, diversified farm production reduced losses and increased farm income streams. Regenerative agricultural practices also gained traction due to being recommended as the best practices. The need to conserve the ecosystem and soil biodiversity through diversified activities necessitated the adoption of RA. Regenerative agricultural practices encouraged nutrient cycling with low external inputs.

The need to control soil erosion, land degradation, and the effects of climate change led to the adoption of managed grazing, crop rotation, intercropping, farm diversity, and organic farming. Furthermore, the need for animal feeds led to the adoption of fodder production. The nature of smallholder farmers in integrating livestock with reduced grazing fields further promoted fodder production.

The efforts to regulate farm weeds and pests with low chemical application attracted integrated pest management techniques, such as push-pull technology, as a cheaper and sustainable option. The need to use resources optimally, including conservation of soil moisture and underground water, also encouraged the adoption of practices like intercropping, crop rotation, and cover crops. The reasons are similar to the findings of other studies in the literature (Burns, 2021; Elevitch et al., 2018; Jayasinghe et al., 2023; LaCanne & Lundgren, 2018; Ranganathan, Waite, Searchinger, & Zionts, 2020). It therefore implies that farmers across different regions are motivated by common factors in promoting agricultural sustainability.

4.1.4. The Challenges in Adopting Regenerative Agriculture in Mixed Farming Systems

The small land sizes limited the scale of RAPs' operations. The practices, such as fodder production, agroforestry, and livestock integration, require large areas of land for economies of scale. Additionally, most RAPs, including organic manure, intercropping, mulching, and diversification, are labor-intensive and initially costly. For example, although sustainable, the cost of establishing a push-pull farm is high. The cost of inputs also posed challenges for practices like crop rotation. Therefore, the farm focused on products for which inputs were readily available. Climate change remains a significant challenge to diversification, crop rotation, and the production of some fodder that does not flower in specific periods.

Furthermore, the mechanization of farm production was a challenge in a regenerative system. The RAPs required reduced farm disturbance, low tillage, less machinery, and fewer chemicals. At times, it reduced management and operational efficiency. Some RAPs, such as mulching and organic farming, were expensive for large-scale operations. Furthermore, they were time-consuming. The impact of RA takes time. Practices like agroforestry, push-pull farming, and legume production take time to regenerate the soil. The pressure to produce staple food limited practices like crop rotation. Coupled with limited land, farmers focused on the main crops, contributing to household food security. Reduced productivity and incompatibility of crops were also reported in intercropping, agroforestry, and fodder production. This resulted from the increased farm competition for soil nutrients and groundwater.

There have also been reports of increased pests and diseases in some RAPs. Practices like zero-tillage, intercropping, and mulching using crop residues have been agents of spreading crop disease. Inadequate skills and knowledge in applying some RAPs have limited adoption and expansion. For instance, low knowledge of push-pull technology and black soldier fly farming has limited its adoption among many smallholder farmers.

The findings are consistent with the existing literature addressing barriers to the adoption and expansion of regenerative agriculture (Gish, Magro, Dionísio, Catarina, & Palma, 2022; Kenny & Castilla-Rho, 2022; Lemke, Smith, Thiim, & Stump, 2024; Tufa et al., 2023). This implies that the challenges facing the adoption of regenerative practices are common across farms in different regions. Therefore, addressing these challenges is vital to ensuring the scalability and sustainability of RA.

4.1.5. Regenerative Agricultural Practices in Mixed Farming Systems

The high adoption of fodder production on mixed farms was associated with the need for feeds for the integrated livestock. Fodder added nutritive value to the animal feeding model to improve productivity. Furthermore, fodder-crop compatibility allowed the integrated cropping system. The ability of fodder to enhance soil fertility, protect the soil as a cover crop, enhance biodiversity, and prevent overgrazing and soil erosion contributed to high adoption. The results are consistent with the literature (FAO, 2015; Omollo, Wasonga, Elhadi, & Mnene, 2018). In the studies, FAO reported that the high adoption of fodder production resulted from the East Africa Dairy Development Project, which promoted improved forage. Similarly, most farms were willing to adopt fodder production due to financial, soil health, and social benefits (Singh, Verma, Gupta, & Chand, 2021).

The high-managed grazing adopted on mixed farms was associated with the farm's deliberate efforts to maintain soil health. Managing a grazing system was crucial in preventing overgrazing, soil erosion, and land degradation, enhancing biodiversity and soil fertility. The rotational grazing system allowed for animal feed regeneration. The results align with the literature (Gusha, Gwapedza, Gwate, Palmer, & Falayi, 2024). The study emphasizes proper grazing patterns to maintain soil fertility.

The high adoption of crop residues as animal feed on mixed farms was associated with the dwindling land holdings that have reduced open grazing fields; therefore, farms used crop residues to supplement the animals' dietary requirements. Various agencies' efforts to encourage nutrient recycling across farm enterprises also contributed to the adoption. It was also a strategy to cut production costs, reduce over-reliance on natural grass, and promote farm crop-livestock integration. The results align with reports in regenerative agriculture (Dumont et al., 2020; Galindo et al., 2020). In these studies, feeding livestock on crop residues is advocated as a nutrient-cycling strategy in farming.

The motivation for high diversification on mixed farms was associated with the need to increase food production, income streams, farm biodiversity, and attain dietary balance. It was also intended to increase nutrient cycling, improve soil fertility, mitigate against climate change, and reduce the risk of crop failure and over-reliance on external farm inputs. The results align with the previous literature on diversification in different regions (Food and Agriculture Organization of the United Nations (FAO), 2019; Makate, Wang, Makate, & Mango, 2016; McCord, Cox, Schmitt-Harsh, & Evans, 2015; Nyamayevu, Nyagumbo, Chiduwa, Liang, & Li, 2024; Sciurano, Arfini, & Maccari, 2024). In the studies, high diversification was motivated by the need to maintain income stability in cases of price fluctuations, pests, diseases, and extreme events that may affect one species.

The high cultivation of legumes on mixed farms was associated with the compatible nature of leguminous crops with other crops as intercrops and their short maturity. The nutritive value of legumes, their contribution to household food security, and the ability of the crops to enhance soil fertility also contributed. Furthermore, some legumes were adopted as livestock feeds. The results align with some of the previous literature (AGRA & IIRR, 2021; Otara, Mogaka, Ndirangu, & Mugwe, 2023). In the studies, legumes were planted as intercrops or cover crops to enhance soil moisture, suppress weeds, control soil erosion, promote the continuation of living roots in the soil, reduce runoff water, assist in carbon sequestration, and fix nitrogen in the soil.

The moderate adoption of intercropping on mixed farms was associated with low farmer training, inadequate inputs to diversify production, over-reliance on cereal crops, management complexity, intensive labor requirements, increased intercrop competition, lack of mechanization, and reduced efficiency in managing weeds, pests, and diseases. The adoption was lower than some previous studies' reports (AGRA & IIRR, 2021; Ntawuhiganayo et al., 2023; Tufa et al., 2023). The higher adoption in the literature was associated with the activities of Farm Africa and the Cereal Growers Association in training farmers on regenerative agriculture through the project of developing a pulses value chain. Furthermore, it was associated with dwindling land, the need for land optimization, diversifying production, enhancing livestock feeds, improving soil fertility, increasing yield, and promoting nutrient cycling. However, lower adoption of intercropping has also been reported (Kirui, Kidoido, Mutyambai, Okello, & Akutse, 2023; Mupangwa et al., 2020; Tufa et al., 2023). This was associated with inadequate training.

The moderate retention of crop residues to decompose on mixed farms was associated with feeding livestock on the crop residue, burning, and using it as mulching material. However, the adoption was moderately higher since it is considered low labor-intensive, with the ability to control soil erosion, conserve soil moisture, and manage weeds. The results align with the existing literature (Anderson, 2009; Kumar, Kumar, & Joshi, 2015). In the studies, there are many benefits to the full retention of stubble on the farm; however, farms burn it, leading to a loss of soil nutrients, soil micro-organisms, and farm biodiversity.

The moderate adoption of crop rotation as a RAP on mixed farms was associated with the pressure to produce staple foods, the small pieces of land hindering the inclusion of some crops in a rotation cycle, the incompatibility of some crops in a rotation system, farms focusing on producing high-demand food, high investment costs in cultivating some crops, and inadequate information about the benefits of crop rotation. The findings were similar to some studies (Chichongue, Pelser, van Tol, Du Preez, & Ceronio, 2019; Kangogo et al., 2021; Tufa et al., 2023). However, the findings were lower than what was reported in other associated literature (FAO, 2019a; Hassaan et al., 2024; Holden, Fisher, Katengeza, & Thierfelder, 2018; Ntawuhiganayo et al., 2023; Tufa et al., 2023). In the literature, a higher crop rotation adoption resulted from training on different farming strategies.

The moderate adoption of agroforestry on mixed farms was associated with inadequate knowledge about the establishment and benefits of agroforestry. Furthermore, small land holdings contributed to the low adoption. The results are closely related but lower than the findings of other studies, Ahmad, Xu, and Ekanayake (2023); FAO (2015) and Kinyili, Ndunda, and Kitur (2020). The higher adoption in the related literature was associated with farmer training on agroecological practices, including natural forests, and the significant perceived benefits of trees on household food production, income, and farming system resilience. However, low adoption was also notable in the literature (Food and Agriculture Organization of the United Nations (FAO), 2019; Jha, Kaechele, & Sieber, 2021; Ntawuhiganayo et al., 2023). This was due to inadequate awareness of the benefits of agroforestry and limited land for production.

The low composting of animal wastes and crop residues as RAPs on mixed farms was associated with the perception that composite manure is ineffective on large-scale operations as organic fertilizer and less productive, limited knowledge of the benefits of preparing organic manure, lack of training on proper composting procedures, intensive labor required, and a lack of sufficient resources for organic farming. Although organic manure is beneficial for sustainable production, if the quantity of manure is low, it may not be sufficient to address soil health and crop needs. Therefore, large quantities are required to improve soil structure adequately. The results were consistent with the existing literature on organic agriculture in developing countries (Holden et al., 2018; Mustafa-Msukwa, Mutimba, Masangano, & Edriss, 2011; Mwaura et al., 2021; Ntawuhiganayo et al., 2023; Paul, Sierra, Causeret, Guindé, & Blazy, 2017). However, some studies have suggested that the use of inorganic fertilizer is the way to address food insecurity in developing countries as a result of quick productivity returns (Boulanger, Dudu, Ferrari, Mainar-Causapé, & Ramos, 2022; Mulupi, Mose, & Sibiko, 2021; Penuelas, Coello, & Sardans, 2023).

The low adoption of mulching on mixed farms was associated with sufficient rain, labor-intensive practices, inadequate skills, and ineffectiveness on a large scale. The results were similar to the findings of previous literature across Africa (FAO, 2019b; Holden et al., 2018; Kakaire, Mensah, & Menya, 2016; Tufa et al., 2023). However, higher adoption was reported in some studies in the literature (FAO, 2019b; Tufa et al., 2023). This was associated with low rainfall and access to training on mulching as a conservation strategy from Farm Africa and AGRA.

The low adoption of zero-tillage on mixed farms was associated with inadequate education and awareness of its benefits, and poor skills and knowledge. The results align with the literature within the SSA (Chichongue et al., 2019; FAO, 2019a, 2019b; Holden et al., 2018; Ntawuhiganayo et al., 2023). However, the areas trained in the practice had a moderate adoption (FAO, 2019a; Tufa et al., 2023). The findings were lower compared to other regions. Seventy percent of the total cultivated area in South America is under zero-tillage. By continent, South America has 46.8% of the global land under zero tillage, North America 37.8%, Australia and New Zealand 11%, Asia 2.3%, Europe 1.1%, and Africa 0.3% (Derpsch, Friedrich, Kassam, & Li, 2010).

The low-water harvesting and irrigation practice was associated with adequate rainfall received in the region, the cost of installing good water harvesting and irrigation facilities, and inadequate technical skills. These results are similar to the literature (Gabriel, 2024; Kebede, 2024; Lutta, Wasonga, Nyangito, Sudan, & Robinson, 2020).

However, low compared to some of the findings from previous literature (FAO, 2019b). Water harvesting and irrigation were moderately higher in Makueni. The higher adoption rates were associated with unreliable rainfall and water scarcity in the region. The low adoption of terracing and ridge construction as conservation farming practices was associated with the practices not being common, as they require specific land terrain and are suitable for particular crop types, e.g., tubers, roots, and fodder that, though farms produce, are cultivated on a small scale and are ineffective on a large scale. Further, the low adoption was associated with the complexity and low returns of the practices, the high labor intensity, and the lack of incentives for farms to adopt. The results are similar to the literature (FAO, 2019b). However, many farmers participated in conservation farming in Makueni County (FAO, 2019b). The higher rate was associated with exposure to regenerative agriculture training.

4.1.6. The Drivers of Regenerative Agriculture Adoption Level in Mixed Farming Systems

Training on RAPs positively influenced adoption. This was associated with the awareness, knowledge, and skills gained in the training. The training sessions are interaction channels between experts and farmers that build confidence and trust in the innovations. It was also established that a lack of information, skills, and experience was among the critical reasons some farms did not adopt RAPs. Therefore, training farmers can be a strategy to create awareness of the practices, transfer knowledge, and share information and experience with the farmers. The results align with the literature on RA and other farming technologies (Coulibaly, Du, & Diakité, 2021; Mustafa-Msukwa et al., 2011; Ntawuhiganayo et al., 2023; Otara et al., 2023; Thangjam, Jha, Sharma, & Singh, 2024). In these studies, training programs assisted in creating awareness and familiarity with the practices among the farmers and informed the applicability, skills, and knowledge, and disseminated the information on the benefits, enhancing adoption.

However, on the contrary, training did not influence the adoption of sustainable farming technology (Hirvonen & Machado, 2024; Karki & Bauer, 2004). The study advocated for other socio-economic factors, including gender and income, to have a greater impact on farm technology adoption. However, the current study emphasizes training farmers to create awareness of the practices, transfer knowledge, and share information and experiences with the farmers. The positive attitude was associated with a creation interest that stimulated the adoption of RAPs. The perceived benefits, ease of practice implementation, the effectiveness of the practice, and affordability were associated with positive attitudes and interest in adopting regenerative agricultural practices. These results are similar to the findings of the previous literature (Beacham, Jackson, Jaworski, Krzywoszynska, & Dicks, 2023; Jayasinghe et al., 2023; Meshesha, Birhanu, & Bezabih Ayele, 2022; Nyairo, Pfeiffer, Spaulding, & Russell, 2022; Tatlıdil, Boz, & Tatlidil, 2008). Therefore, there is a need to create awareness of the advantages of regenerative agriculture to induce a positive attitude among farmers.

Having experienced the high benefits from RAPs positively influenced adoption. This was associated with increased farm productivity, diversification of farm output, enhanced soil fertility, reduced production costs, reduced farm external inputs, increased animal feeds, suppressed weeds, enhanced biodiversity, quality food products, increased income, and reduced soil erosion derived from the RAPs as the drivers and motivators to expand the adoption. These results align with the previous literature on regenerative agriculture (Elevitch et al., 2018; Giller et al., 2021; Jayasinghe et al., 2023; Lemke et al., 2024; Newton, Civita, Frankel-Goldwater, Bartel, & Johns, 2020; Otara et al., 2023; Schreefel et al., 2022; Schreefel et al., 2020). Therefore, the benefits of RA are one of the key adoption drivers. A farm producing food crops alone positively influenced the adoption of RAPs. This was associated with low adoption of RAPs in commercial production. Cash crops are highly monocropped and are produced under intensive systems with synthetic inputs. Regenerative farming practices work better for non-commercial production. It is a system that works overtime to enjoy the benefits; therefore, it is not effective for commercial production. The compatibility of the types of crops produced on a farm will determine the extent of intercropping, rotation intensity, agroforestry, and crop rotation patterns. It was established that some farms did not practice regenerative agricultural practices such as intercropping due to the problem of crop incompatibility, pressure to produce staple food, and perennial crops reducing crop rotation intensity. Therefore, including specific crops in the rotation patterns, such as legumes and fodder, accelerates soil fertility regeneration (Khangura et al., 2023). This conforms to the previous literature (Khangura et al., 2023; Newton et al., 2020; Pandey, 2001).

Owning land positively influenced the adoption of RAPs. Land ownership enhances land use mobility, which is crucial in decision-making about adopting and investing in RAPs. The results are consistent with the findings of (Ahmad et al., 2023; Tatlıdil et al., 2008). The researcher reported that the willingness to participate in agroforestry and other conservation practices increases when a farmer owns land. Land ownership guarantees the long-term economic viability of regenerative agriculture, as future returns are secured, and therefore increases the willingness to invest in these practices (Mwaura et al., 2021).

A farm that benefits from a subsidy program positively influences the adoption of RAPs. The subsidies are financial boosts to encourage farmers to adopt the practices even when the yields are still low. The results align with the existing literature (Lemke et al., 2024; Pathania et al., 2024). In this study, a subsidy program provides inputs and extension services at a reduced cost, motivating farmers to practice sustainable farming practices. According to the World Business Council for Sustainable Development (WBCSD) (2024), during the transition from a conventional farming system to regenerative agriculture, farmers lose up to about USD 40 per acre, and subsidy programs are crucial at this stage to encourage continuation. However, on the contrary, if synthetic inputs are subsidized, an intensive system will accelerate biodiversity loss (World Business Council for Sustainable Development (WBCSD), 2024).

5. CONCLUSION

The current study addressed the low regional contribution of RA products to the global market, caused by the low adoption of RAPs. The paper focused on characterizing and evaluating the drivers of RAPs in mixed farms. The RAPs were evident in the mixed farms. They were implemented to enhance soil fertility and nutrient cycling, reduce land degradation, optimize resources, manage pests and diseases, and boost livestock feed production. Fodder production, managed grazing, feeding livestock on crop residue, farm diversification, and legume production were highly adopted. Intercropping, retention of crop residue on the farm, crop rotation, and agroforestry were moderately adopted. Composting, mulching, zero-tillage, organic farming, water harvesting, irrigation, terracing, ridge construction, and integrated pest management had low adoption. The RAPs are implemented differently, for different reasons, and experience varying challenges. However, the reasons for adopting and the challenges experienced in RAPs are largely common across the farms. The drivers of RA adoption include training, farmers' attitudes, benefit level, land ownership status, crop type, land size, farm fertility status, and participation in subsidy programs. Therefore, farmer training, subsidy programs, and processing of land title deeds are recommended as strategies to accelerate RA adoption. This will enhance the regional contribution to the global RA product market.

The study was limited as it did not include a comparative analysis with farmers who do not participate in regenerative agricultural practices or those who do not practice a mixed farming system. The study suggests that similar studies be carried out in other counties in Kenya and in the region to establish a complete picture, variability, and similarities.

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